III. "On some Phenomena in Vacuum-tubes." By Sir DAVID SALOMONS, Bart., M.A., V.-P., Inst. Elec. Engrs. Communicated by Prof. D. E. HUGHES, F.R.S. Received April 30, 1894.

This paper is a contribution upon the phenomenon known as striæ, or bands, in vacuum tubes.

As far as I can learn from the sources of information available to me, no one has yet discovered how to produce a predetermined number of bright and dark bands in a tube having an open or free path.

After a prolonged investigation I have succeeded in producing this result.

This first step having been attained, it is evident that a number of experiments are available for confirming the theories at present held in regard to the subject, or possibly for modifying existing views, or even to form some additional theory, if necessary.

I do not think that it would be judicious, at the present stage of my experiments, which are by no means complete, to enter upon any theoretical considerations, although some conclusions might suggest themselves which, however, until the work has been greatly extended, would possibly lead to error.

It would appear that the main efforts of those experimenting with vacuum-tubes have been in the direction of securing very high exhaustions and using currents of very high electromotive force. In many cases also currents having a high frequency have been employed.

When I began these investigations, about twenty years ago, the chief difficulty was to know at what point to commence. After due consideration I decided upon the following course:—

A very large number of vacuum-tubes were "lit up," and all tubes which showed a somewhat similar phenomenon were carefully examined, and their characteristics noted. It is probable that the number of tubes so examined considerably exceeded a thousand, perhaps several thousands.

At last it became quite clear that, to produce a definite phenomenon, the tube must be given some definite characteristic; and having settled this point I was enabled to start upon a systematic investigation.

There is no object to be gained by detailing the reasons which led me to work in the manner I did, and, therefore, I will be content to give the results.

When I use the word vacuum-tube I employ it in the ordinary sense. In all the experiments to be described the tubes contain ex-

hausted air, and the current employed is an alternate current. The experiments here mentioned must, therefore, be regarded as a first instalment. They will have to be repeated, with an intermittent direct current and with tubes containing various gases, and probably also tubes containing various vapours, and all these at various exhaustions and temperatures.

I have already made a large number of experiments employing tubes containing different gases and with direct, as well as alternate current. I may, therefore, mention that the phenomena about to be described, when using the alternate current, appear to be the same with the direct current, except that the phenomena peculiar to direct currents, in the form of the bands, make themselves apparent. But, until these experiments have been completed, I will not refer to them any further in this paper. I find it necessary to work in the contrary manner to that which is usually adopted.

1. The alternations are made so slow that blinks are produced in the tube under observation, which correspond to the reversals; and then the alternations are increased in speed until the tubes appear continuously lightened. This is my starting point. I have the means of raising the frequency when desired. The apparatus for producing the alternate current, in the first instance, is a Pyke and Harris alternator driven by an electromotor, hence as the frequency increases so does the electromotive force; I am therefore obliged, when describing the experiments, to employ the expression "electric energy" or "current" in order to avoid confusion.

2. Since I use currents of such low frequency the electromotive force also is very low; and the quantity of current traversing any tube is small.

3. The tubes are not very highly exhausted, they are only exhausted to approximately 0·5 mm. of mercury, according to the usual mode of comparative measurement. But I find that, whether the tubes are highly exhausted or not, provided the current passes, all the phenomena are the same. At a very early stage of the investigation I observed that the ordinary methods of working, *i.e.*, with currents of high electromotive force, masked the effects I was seeking.

In giving the subject a logical sequence so that each step may be noted, I have no doubt that I shall describe several effects which are already known. But to omit these, which I am unable to single out, would be to lose the thread of the history.

In a scientific paper it is usual to prove some definite point or to show some special new phenomenon. It is therefore desirable to point out the object aimed at in this communication.

The object I originally had in view was simply to discover a method by which vacuum-tubes could be made to give a prede-

termined number of bright and dark bands, as it appeared to me this would be the first step in examining the laws which govern their production. In this I succeeded at a very early stage. But, in order to make the proofs more convincing, other experiments were entered upon which brought to light a number of new points of considerable interest; and many of these experiments appeared to throw considerable light as to the origin of the bands.

The object of this paper, therefore, is, first, to show the methods by which a definite number of bright and dark bands can be produced in a vacuum-tube; and, secondly, to describe a number of interesting phenomena which have a bearing on the production of the bands in general.

The first step is to describe the apparatus employed in making the experiments. A small direct-current motor is coupled directly to the smallest sized Pyke and Harris laboratory alternator. The alternate current produced can be made to vary its E.M.F. according to the speed given to the motor and also by varying the exciting current. The E.M.F. of the alternate current can be made variable from 0 to 100 volts, and the maximum current which the machine is intended to give is 3 ampères. The pressure of this current is raised by means of a Pyke and Harris oil transformer or with a Salomons and Pyke combination transformer. Sometimes one form of transformer is used and sometimes the other. It is usual to give the exact electromotive forces of the current employed, as well as its periodicity, but in the following experiments it is not necessary that this should be known accurately, from the very nature of the experiments, because, as already mentioned, the experiments were started with exceedingly slow alternations and a very low E.M.F., which were gradually raised, the phenomena being watched throughout as they varied.

It is essential that the speed of the motor should be under complete command, and that the speed should be made variable during any experiment. To attain this end I employ a Kelvin rheostat and a Wirt rheostat.

All the tubes employed, so far as their exterior form is considered, may be regarded as practically of one type; long tubes of varying lengths and large diameters, many of them containing small devices which consist of little glass disks, glass rods, and other arrangements for modifying the nature of the electric discharge, and, for want of a better name, I term them "deflectors." Although, perhaps, the word "moderator" is more applicable, it has another meaning, and its employment here might give rise to confusion.

In many of the experiments to be described the bands appear to be repelled from some part or parts in the tube towards the electrodes. I feel some difficulty in selecting language suitable for de-

scribing this effect, for although to the eye repulsion is evident, it may not, from a scientific point of view, be correct in fact. The appearance may be explained in a variety of ways, but in order to simplify description of the experiments I treat the appearance as a repulsion. However, it must not in consequence be inferred that repulsion really does take place.

The experiments are here given in their logical order, although in point of fact they were not originally made in this sequence. In all investigations it occurs almost invariably that an experiment is made which suggests the previous steps that are necessary to obtain a logical order, and indeed some of these steps are frequently unobtainable. Therefore, it is very probable that what I believe at present to be the sequence may yet have missing links.

Some of the conclusions which may be drawn from the following experiments are :—

That bands may be produced with greater facility in small tubes than in large, and that they become more accentuated probably on account of the inequality of the diameter of such tubes.

That for the production of bands, the glass of the tube itself appears to play a part, since the bands are difficult to produce unless they reach to the glass of the tube.

That an exceedingly minute current produces bands which to the eye, in most instances, disappear when the current is somewhat increased, and on further increasing the current they become visible again. I believe that in all previous investigations it has been stated that the bands cannot be produced until a considerable current is passed. I refer to investigations by Messrs. Warren de la Rue, Gassiot, and others. My experiments prove the contrary. The probable reason why these statements were made is due to the fact that with the apparatus employed at that time such small currents could not be easily produced. When the minute current is increased, and the bands seem to disappear, I think this is only an optical illusion; the bands are there, but too faint to be seen, perhaps in consequence of the dark bands being so narrow that they escape observation.

That, when an electric discharge takes place in a large tube in which is placed a partition pierced with a hole, "a forcing effect" frequently appears to be produced. Any bright bands being produced at the hole in the partition may give the appearance of being pushed through to the side of the tube which has the greater length. This phenomenon is mentioned because it is apt to mask many effects, unless the current is suitably adjusted.

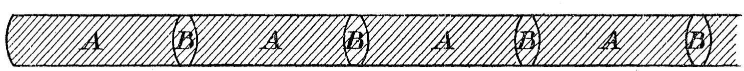
That it is not impossible, after the first trace of light becomes visible in a tube when passing a very minute current, that the dark bands subsequent to this stage are illusory, and that they are really

the bright bands; and what appear to be the bright bands consist of overlaps which produce double the brightness of the so-called dark bands. In reality, therefore, the bright bands indicate the position of the dark bands. (See fig. A.)

Case 1.

A = Bright bands. B = Dark bands.

Case 2.



Bright bands A expanded overlap at dark spaces B, which now appear twice as bright as at A, and the spaces A appear dark by contrast.
FIG. A.

That by devices bands can be produced in a large tube occupying only a small portion of the cross sectional area, at any rate so far as the eye can discern.

That, when employing Professor Crookes' tubes for illustrating experiments on radiant matter, if suitable conditions are observed, striæ are formed in these tubes.

That, in tubes having exceedingly small electrodes, and apparently not capable of producing striæ, these can be shown to exist if very minute currents are employed.

That the tube, when made to act as a condenser, permits more current to pass.

That from the above considerations it is not unlikely that a view, which has been held, in regard to the probable origin of the bands, that they consist of a series of discharges through the tube, is true; that the nature of such discharge can be varied by suitable devices placed within the tubes, and that the examination of the nature of the discharge can be best made with very minute currents, that is to say, currents so small that, if made any less, the tube would no longer show any sign of light.

(N.B.—The number against each figure corresponds with the number of the experiment. This accounts for the absence of fig. 10. The experiments were made with the tubes supported horizontally (with the exception of tube fig. 12). This position was chosen for the sake of convenience, the results being the same for all positions. Tube fig. 14 must be placed horizontally in order to shift the movable disk).

Experiment 1.

A plain tube of large diameter with aluminium brush electrodes at the ends is employed. (See fig. 1.) On passing an electric discharge, with very slow alternations, at first the tube appears dark, and the speed of the alternator then being slightly increased, the light just becomes visible within the tube, and there is seen a few bright bands with dark spaces intervening. These bands are convex, the convexity being towards the centre of the tube in all cases. The bands do not extend to the centre of the tube, consequently the convex sides of the bands at each end of the tube face one another, and do not meet in the centre of the tube. The motor is then stopped, and the falling light in the tube is carefully watched. It can then be noticed that the moment before the current dies out, and the bands disappear, one or two more appear nearer to the centre. On the other hand, if the current is increased the bands are driven towards the electrodes until they disappear altogether. The tube is then simply lighted throughout.

The experiment is now repeated when a current is adjusted to produce the bands, and the centre of the tube is placed to earth by resting the hand upon it or in any other convenient manner, when it

Fig. 1.

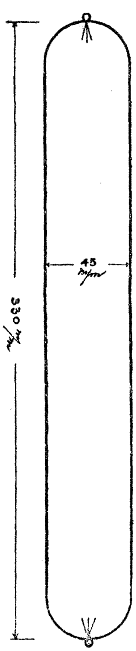
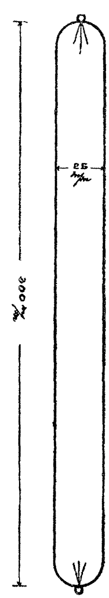


Fig. 1a.



will be observed that the bands approach towards the centre, but still do not fill the tube; sometimes one or two new bands appear. It is difficult at present to say why this should be the case, for, apart from other views which may be taken, the following two conditions might exist:—

1. If the apparent repulsion of the bands is due to the electrification of the glass of the tube, then an effect is produced somewhat similar to that in the gold leaf electroscope, and by placing the hand upon the tube, a discharge being produced, the bands will approach in the same way as in the case of the leaves of an electroscope when discharged, but the glass being a bad conductor, the discharge is partial only.

2. The view might be taken that when the hand is placed on the tube a condenser is formed, and the surface of the glass within the tube becomes more highly electrified, and the approach of the bands is due to this cause. If this explanation is true, the ocular effect of repulsion is not really due to repulsion.

The condenser action appears to be confirmed by my experiments, and is very prettily shown in the following manner:—

Adjust the current in any vacuum tube until the discharge is just visible. Now carefully reduce the current until the tube is dark, *i.e.*, when there is no visible discharge. If the hand is now placed on the tube the latter will light up brightly. If the adjustment is made with sufficient care, the very fact of placing the hand within an inch or so of the tube will cause it to light up as if by magic. The repulsion effect may also be true, although it appears to me evident that more current flowing into the tube, when the outside is earthed, is in no way caused by any discharge from the interior of the tube.

A tube is now taken of much smaller diameter, 25 mm., the bands will now be formed the whole length of the tube; other phenomena are the same as with the large tube. (See fig. 1A.)

Experiment 2.

A similar tube was employed, but it contained in the centre of its length a very slight glass rod, attached to the side, supporting a short thick glass rod lying along the axis of the tube (see fig. 2, where dimensions are given, as in the case of other figs.). The object of this experiment is to see whether the repulsive effect would be increased; or, if not increased, whether the phenomenon could be made more clear. The latter proved to be the case. In passing the current in the same manner as in the previous experiment, bands were formed throughout the length of the tube, one appearing at the centre of the little rod and one at each end or near the ends of the rod. On in-

Fig. 2.

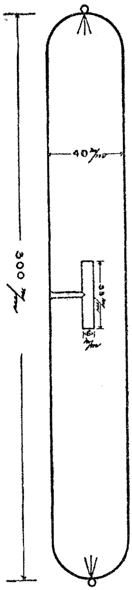
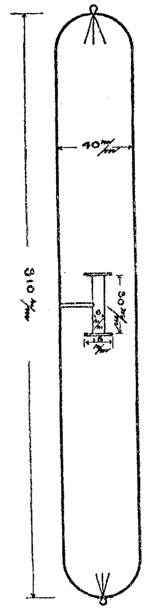


Fig. 2a.



creasing the current the bands are driven towards the ends of the tube. A point is reached when the rod is clear of bands, only one appearing at each end of the rod. Still further increasing the current the bands are farther driven back until at last the tube appears filled with light without any trace of striæ. From these two experiments I conclude that, in a large number of cases, the phenomenon of bands is masked in consequence of too much current being employed. Similar tubes, with glass discs at the end of the rod were used, and with same effect, see fig. 2a. Some of the experiments which follow clearly explain how this masking effect is produced.

Experiment 3.

It is well known that a bright band is formed at any little projection placed within a vacuum-tube. For instance, if a rod of glass is placed within such a tube along its axis, and has upon it little beads of glass or any other material, a bright band will be produced at these places. It appeared to me that, from Experiment 2, it was not improbable when considering the "repulsion effect" that these bright bands really consist of a pair in close contact.

In order to examine this question more closely I use a tube (fig. 3) which contains two thin glass disks placed upon a glass rod at one end of the tube. On passing the current, sufficient to light up the

tube, a distinct bright band is seen on each side of each glass disk. Several tubes are used in this experiment, and in many instances by lowering the current the time arrives when the two bright bands, on either side of a disk, appear as one. When the current is increased these bands leave the edges of the disks to some distance from them, as if they are repelled one from the other in consequence of more current flowing through the tubes and creating a greater electrification, if it be due to this cause at all.

It is further seen that throughout the free portion of tubes con-

Fig. 3.

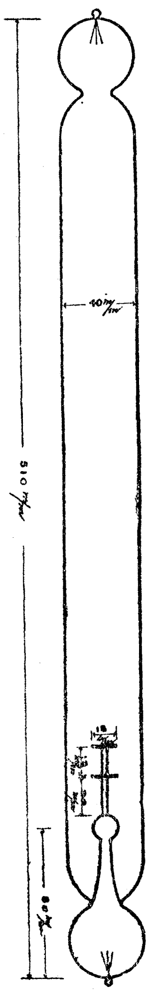


Fig. 3A.

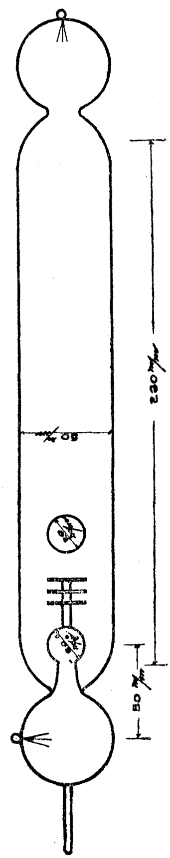
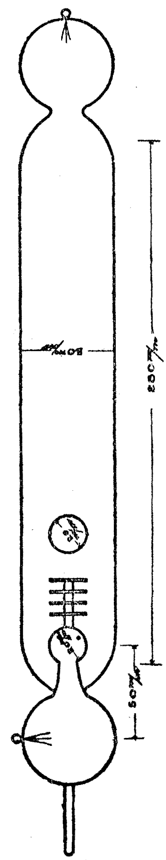


Fig. 3B.



structed in this manner, the bright bands are repeated along them, the distance corresponding with the distance between the bright bands formed at each side of any disk. On increasing the current, very considerably in consequence of the bands on the glass disks receding from the latter, a confusion is set up throughout the tube, *i.e.*, the bands all mix together, especially as they become somewhat wider at the same time as they recede from the glass disks, till finally the whole tube appears generally lit without any bands being seen. Some tubes will melt before obtaining this effect.

I, therefore, conclude that the absence of bands is generally due to this cause, *i.e.*, the bands are really there, but in consequence of too much current they have become expanded and overlap one another so often as to render their existence invisible. Some very instructive experiments for the examination of this effect will shortly be described.

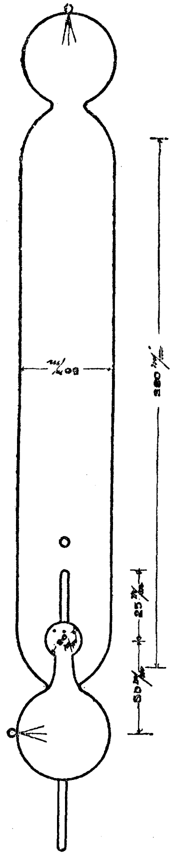
Tubes with three and four disks on the rods were also used, and these produced similar effects. (See figs. 3A and 3B.)

Experiment 4.

This experiment and some of those which follow are made with a view of determining the possibility of producing a given number of bands in a vacuum tube. The possibility of doing this might already be inferred from the experiments described. If it is generally true that any two bands produced at one end of a tube are repeated throughout the tube at the same distance apart as the first pair formed, and if it is true that any impediment within the tube will produce a pair of bands, then the problem is solved; and I think the following tubes show that such is the case.

The tube shown in fig. 4 has its ends contracted and re-expanded into bulbs, in which the electrodes are placed. At one end, where the contraction exists, a short tube is melted on, which carries a little hollow sphere of glass with three holes so situated that, if a line be drawn from the centre of any hole to the centre of the glass sphere, an angle of approximately 45° is made with the axis of the tube. There is melted on the top of the glass sphere a short rod projecting into the free part of the tube, the axis of the rod coinciding with the axis of the tube. When the current is passed there *should* be formed a bright band at the base of the rod close to where the current issues from the three holes in the sphere, and another one at the free end of the rod. Then throughout the tube there *should* be produced bright bands equidistantly placed, such distance being equal, or approximately equal, to the length of the little rod; and, on passing the current, this proves to be the case. When the amount of current passed is exceedingly small, distinct, narrow, bright bands become

Fig. 4.



visible, with absolutely dark, wide spaces between them. On increasing the current, the bright bands expand, the dark spaces growing narrower till at last the bright bands touch one another and then overlap. Then the paradox occurs that the dark bands appear bright and the bright bands appear dark; *i.e.*, the bright bands overlap where the dark spaces should be, and therefore appear doubly as bright as the remaining portion of the bright bands, which now appear dark by contrast.

From experiments conducted on other tubes I think it is quite clear that this is the usual condition of things, and that it is exceedingly rare that the true black bands are really seen. But in this experiment there is one point of interest which must not be overlooked. It is, that whether the current be small or large, the rule set up by the little rod at the end of the tube cannot be upset. The

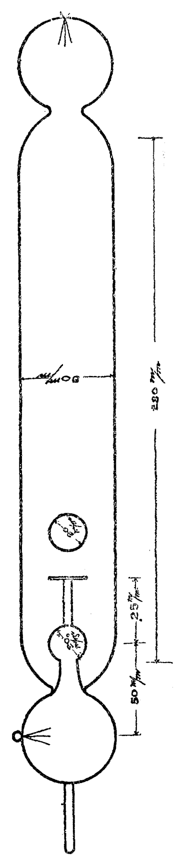
number of bands in the tube will not advance nor recede, nor alter their number in any way; neither can they be made to disappear by increasing the current as in other cases. The only thing that happens is that the bright bands grow wider as the current is increased till the paradox referred to is apparent.

This same experiment is made on a number of tubes built in a similar fashion, but having different dimensions. The result, however, is always the same. The overlapping of the bright bands may occur again and again, so that the dark spaces are first bright, then dark, then again bright, and so on, until the tube is destroyed by the excess of current passed.

Experiment 5.

I find that if a tube is employed similar to that in the last case, but with a glass disk placed at the end of it (see fig. 5), the same

FIG. 5.



result follows. The object of this experiment was to see whether the glass disk would set up its own bands independently of those due to the rod, but the rod appears to gain the mastery. Probably the two bands formed by the glass disk are driven (or repelled) into one by the rod.

Experiment 6.

I next tried the effect of contractions to see whether the same result would not be produced as if the deflector rod were employed. Several forms of tubes are used: in some cases a little glass sphere, as described in the previous experiment, without the rod attached to it; in other cases the tube was contracted for a definite length and then expanded; in other cases disks of glass and of mica were inserted with holes in the centre, as shown in figs. 6, 6A, and 6B. The same results are produced as with the rod; the distance of the bright bands apart being equal, in the first tube, to the distance between the holes in the glass sphere and its electrode; in the second tube, to the length of the contracted tube; and in the third tube, to the distance between the holes in the disk and its nearest electrode.

When a tube, containing a glass or mica screen with a hole in it, is employed, one of the three effects may be produced:—

1. Broad bands throughout the tube, as already mentioned.

2. Very narrow bands, their distance apart being equal to the distance between the two bright bands formed on both sides of the screen in the tube.

3. No bands in the tube, or only a confusion of bands, and no distinct bands on either side of the disk. Unless this circumstance were pointed out, it might prove misleading to anyone trying the experiment. I tried a large number of tubes built up in this manner, in order to discover the cause of the different phenomena.

It would appear that broad bands are produced when the distance between the disk and its nearest electrode is suitably adjusted. If the screen is placed far away from the electrode, bands are produced on each side of the disk, and they are reproduced throughout the tube. If the screen is placed nearer to its electrode, the two disks appear to be driven into one, and broad bands are produced. If the screen is placed still nearer to the electrode, then what should be the two bands on either side of the disk are driven through the hole, and appear as a hemisphere of light on the side of the tube which is the longest. In this case bands may or may not be produced, and, if present, they are irregular.

These three effects can be produced by varying the current in many instances, and very probably in all cases; but, as a rule, the tubes break down before all the effects can be shown.

Again, plain tubes are employed with electrodes of varying lengths.

FIG. 6.

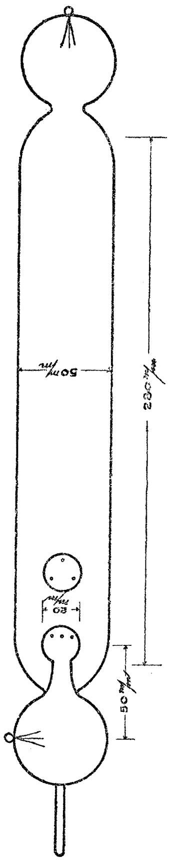


FIG. 6A.

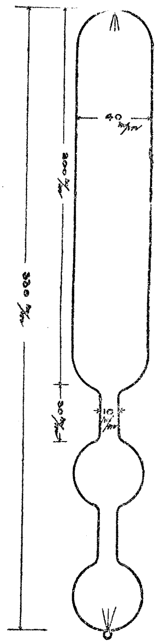
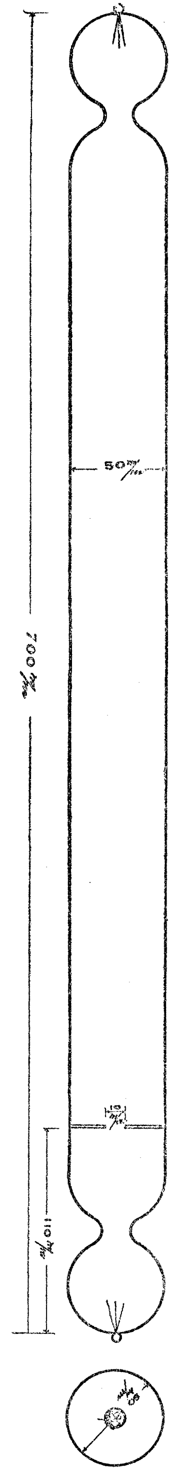


FIG. 6B.



The length of the electrode acted in the same way as did the deflector rod in Experiment 4. It is, therefore, clear that in arranging Experiment 4 it was necessary to have the length of the rod some multiple of the distance between the holes in the glass sphere and its electrode; also that the length of the glass rod should be some definite multiple of the distance between the contraction of the tube at the farther end and its electrode; also that the length of the electrodes should be short compared with any of these distances; otherwise a confusion of bands would be set up.

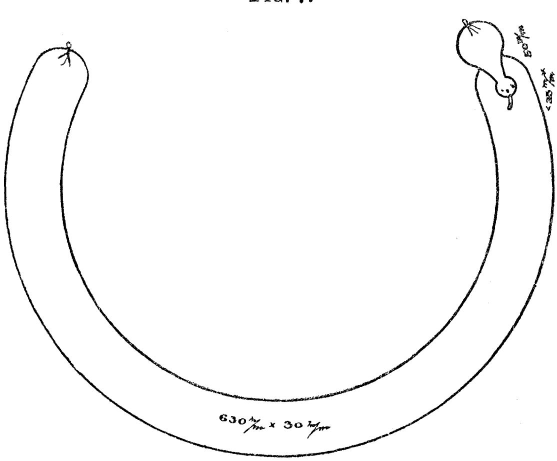
The experiment with the disk of glass placed at the end of the deflector rod showed that any effect which could be produced by this disk alone was overpowered by the effects produced by the rod. This would appear evident, since the two bands which would be formed by the disk would practically be driven (or repelled) into one by the action of the rod; the independent action of the electrodes in the case of Experiment 4 being absent may be due to the same reason.

I had considerable difficulty in getting over these points, for, at first, confused results were presented in some tubes and not in others, and it was only after investigating the matter, as here mentioned, that I was able to construct tubes without difficulty to give definite results when these various details were attended to.

Experiment 7.

Various forms of curved tubes are tried, some of them bent almost into a circle. In several instances the little hollow glass spheres with short rods bent to the curve of the tube are inserted, and in other

FIG. 7.



cases screens across the tubes with holes in them, and other tubes similar to those already described, the object being to see whether the effects produced are the same as if the tubes had been straight, and this proved to be the case. One tube is shown in fig. 7.

Experiment 8.

This one consists of a number of tubes containing no devices of any kind. But in one case there are two electrodes at one end, and one electrode at the other end of the tube. In another case a tube has two electrodes at each end. Another tube has very small electrodes, while others have various sizes of electrodes. In all these instances bands are produced, but the smaller the electrodes the less current has to be passed to show the bands, and the closer they appear together. (See figs. 8 and 8A.)

FIG. 8.

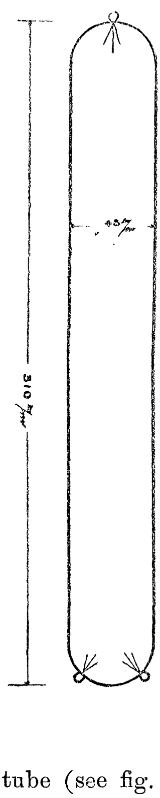
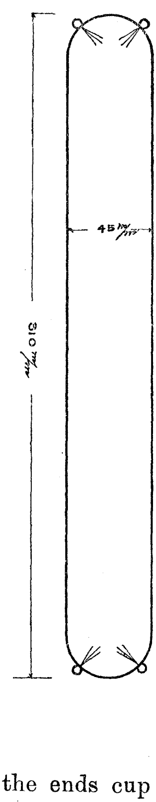


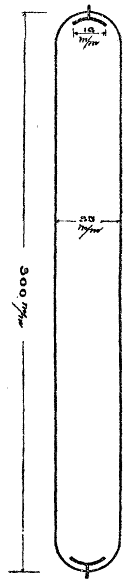
FIG. 8A.



Experiment 9.

A plain tube (see fig. 9) has placed at the ends cup electrodes, about 16 mm. in diameter, close on the glass. In appearance the

FIG. 9.



electrodes are like two small concave mirrors. When the current is passed, the effects produced are somewhat similar to a "radiant-matter tube," *i.e.*, the light produced by the discharge converges and the tube is generally lit up. The current is now diminished, and at a certain point bands make their appearance.

Experiment 10.

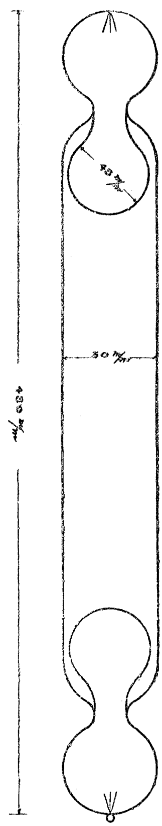
Following the last experiment, I tried a number of tubes constructed to show Professor Crookes' radiant matter phenomena. I find that if the current is sufficiently diminished the streams of light break up into bands. I am not aware whether this circumstance is known.

It ought to be mentioned that in some cases the effects can only be observed by passing a considerable quantity of current through the tube and then turning off the alternator, so that it runs slower and slower until it stops. The light in the tubes gradually diminishes until they are dark. Many effects can only be observed at the moment of extinction. Some tubes, in which it appears impossible to show the bands, give the phenomenon most distinctly at the instant referred to.

Experiment 11.

Tubes are employed as shown in fig. 11. They consist of plain tubes, the ends of which are expanded into bulbs that contain the

FIG. 11.



electrodes. Glass balls are blown on the contracted portions, so that these glass balls become the electrodes for the tube proper wholly and solely by induction, there being no connexion between the glass tube proper and the electrodes, except through the glass of these balls. Again the effects produced are the same as if the current were passed without the inductive process, *i.e.*, the bands are produced in a similar manner.

Experiment 12.

It has already been said that the glass itself appears to assist in the formation of the bands. This may be due to the electrification of the glass or to some other circumstance. In any case the bands have a tendency to stick to the glass with some pertinacity. The most convincing way to show this is by means of a tube lit up by induction in a manner similar to the type of tube employed in the experiment last described. A tube is employed with inductor electrodes consisting of glass balls, but the main tube consists of one contracted near the glass balls and then expanded, in the centre of its length, into a large sphere (see fig. 12). When such a tube is lit up the results must be looked for in the large glass sphere. It will be noticed that bands are formed at the entrances to the sphere, somewhat parabolic in shape, *i.e.*, the centres of the bands appear driven towards the centre of the sphere, while the edges of the bands seem to stick to the glass and to be retarded. On increasing the current the bands expand somewhat, and become slightly more numerous, and eventually a few of the most forward ones suddenly leave the glass sides and agree with the equatorial plane. (Figs. 12A and 12B give a rough idea of the two stages.)

Experiment 13.

To further illustrate the action of the glass in the formation of bands, a long tube is employed with a number of bulbs blown along the length of the tube at short distances apart. (See fig. 13.) On passing the current, bands are formed along the whole length of the tube, excepting at those places where the spheres are blown. At these places the bright bands disappear. If the current is considerably increased, the bright bands enter a certain distance into the spheres. These are not independent bands, but those driven out of the straight portions of the tube (the bands having become expanded), which is very easily observed when adjusting the current and watching the tube.

Experiment 14.

Professor Fleming suggested that, in order to make some of the experiments more convincing, the open tube and tube with a disk should be combined.

I therefore employed a tube shown in fig. 14 for this purpose. The tube is a plain tube, and at one end, 40 mm. from the electrode, a glass disk is hinged from the side of the tube. This disk may lie flat on the tube or stand vertical (as shown in the diagram) at pleasure, by tilting the tube or by turning it upon its axis. This tube must be placed horizontally in order to raise or lower the disk.

Fig. 12.

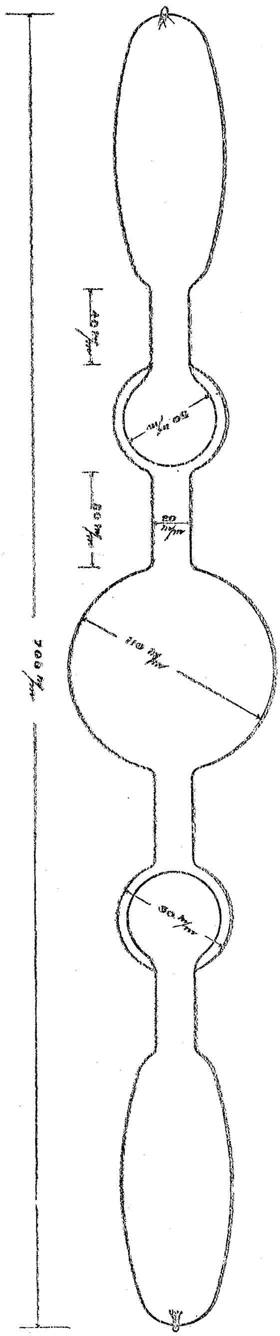
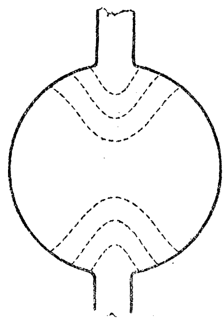
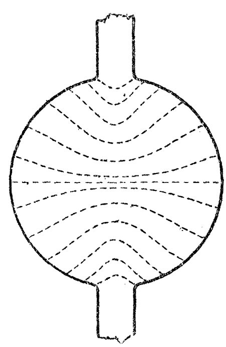


Fig. 12a.



First stage.

Fig. 12b.



Second stage (more current passed).

FIG. 13.

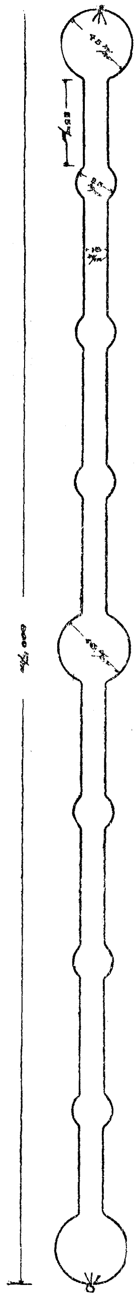
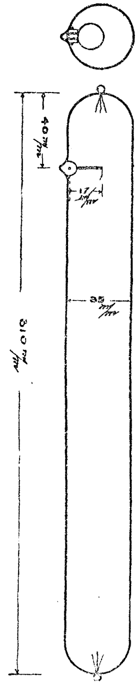


Fig. 14.



The phenomena of a plain tube are shown when the disk is down, and when up the regular bright bands are produced. This experiment is very striking.

IV. "On an Instrument for Indicating and Measuring Difference of Phase between E.M.F. and Current in any Alternating Current System." By Major P. Cardew, R.E. Communicated by Lord Kelvin, P.R.S. Received June 21, 1894.

If the periodic time of an alternating E.M.F be T, and if, owing to the presence of capacity or self-induction, or both in the circuit, the current passes through the value O at times differing from the times of passage of the E.M.F. through the same value by t, the electrical power will be $V \times C \times \cos(2\pi t/T)$, where V indicates the effective volts and C the effective current.

If a momentary contact be made at intervals exactly synchronising with the period of the alternating E.M.F. to complete the circuit of a suitable and suitably connected galvanometer, and if the time of